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(54) Digital communication system using partial response and bipolar coding techniques.

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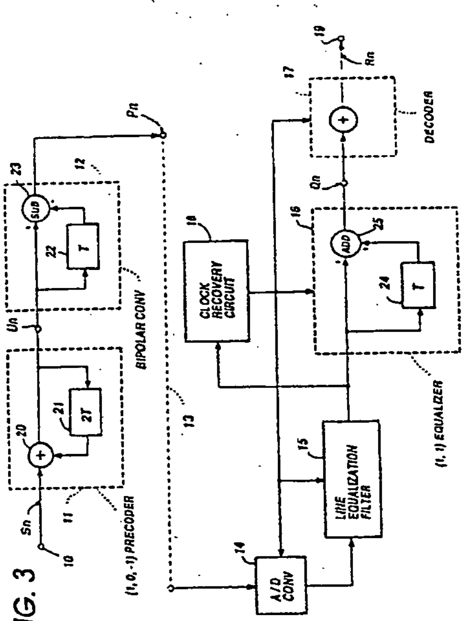

FIG. 3

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Digital Communication System Using Partial Response and Bipolar Coding Techniques

The present invention relates generally to a digital communication system for transmitting a digital signal over a metallic cable having a transmission attenuation characteristic $\sqrt{f}$.

With the introduction of advancing technologies in data terminals, they are now capable of operating at a speed on the order of megabits per second. Various networks have been developed to allow efficient transmission of data between high performance data terminals. Most of these networks employ optical fibers as transmission media. Although satisfactory for transmitting such high speed data from data terminals to network access points, optical transmission media require the use of optical transceivers which significantly increase the cost of the data terminals. One simplest method to overcome this problem is to employ twisted wire pairs. However, signals transmitted on wire pairs attenuate significantly as the frequency of the signal increases as is known by the formula $\sqrt{f} \cdot l$, where f is the frequency of the signal being transmitted and l, the length of the transmission line. Multilevel signalling and partial response signalling are known efficient methods for transmitting high speed data over a twisted pair of wires. However, multilevel signalling requires an adaptive equalizer at the receive end of the system to automatically suppress intersymbol interference (at sample points) which noticeably increases in applications which transmit signals having four levels or greater. Since the adaptive equalizer needs to perform discrete control on sample values if high precision operation is required, the hardware necessary to implement such requirements would significantly increase in volume. Partial response signalling solves this problem. For a given number of signalling levels, a comparison between multilevel signalling and partial response signalling indicates that the latter is more advantageous for use with transmission lines having the $\sqrt{f}$ attenuation characteristic. However, the partial response technique overfilters the encoded signal and so it limits the spectrum of transmission narrower than the Nyquist bandwidth ($f_0/2$, where f_0 is the symbol clock frequency). This results in a data bit stream having a small amount of clock components and makes it difficult for a nonlinear clock recovery circuit to generate the necessary timing signal.

From the clock recovery view point, bipolar coding technique is suitable. Since a signal is said to have ample clock components if it exhibits a high energy spectral density in the neighborhood of frequency $f_0/2$, the bipolar coded signal is the case in point. However, the bipolar signal has a greater range of mainlobe energy density than in the case of partial response signalling and so it requires a wideband equalizer, which results in a low signal to noise ratio. In addition, because of the three-level signalling, the bipolar coding adds complexity to the problem of signal to noise ratio.

Fig. 1 is a block diagram of a prior art digital communication system employing a (1, 1) partial response signalling scheme (which is known as a class-1 partial response signalling). An input binary digital data stream a_n with symbol clock intervals T is passed through a precoder 45 formed by a delay line of length T and a modulo-2 adder and encoded with an intermediate data stream b_n (where n is a sequence number identifying each symbol). The intermediate data stream b_n is converted by a (1,1) conversion circuit 46 into a (1,1) multilevel data stream c_n which is transmitted through a transmission line 47 to an analog-to-digital converter 48 at the receive end of the system. As shown in the drawing, this (1,1) conversion circuit is made up of a delay line of length T and an adder. The (1,1) multilevel data stream c_n is converted by the analog-to-digital converter 48 into a digital signal and fed to a transmission line equalizing filter 49 to compensate for the transmission loss. The output of the equalization filter 49 is applied to a decoder 50 where the input signal is converted to an output digital data stream d_n which is a replica of the original data stream.

The following relations hold between the data streams a_n, b_n, c_n and d_n:

$b_n = b_{n-1} \oplus a_n$

$c_n = b_n + b_{n-1}$

$d_n = [c_n]_{mod2}$, (where $d_n = 0$ when c_n is even, $d_n = 1$ when c_n is odd), where $\oplus$ represents modulo-2 summation.

If $\{a_n\} = \{101100101\}$, then

$\{b_n\} = \{110111001\}$

$\{c_n\} = \{121122101\}$, and

$\{d_n\} = \{101100101\}$.

As shown in Fig. 2a, the spectral component of the (1,1) partial response signalling code at one-half the clock frequency is significantly small, making it difficult for the receive end of the system to recover clock timing signals. On the other hand, the bipolar encoded signal has a spectral peak at one-half the clock frequency as shown in Fig. 2b, indicating that the bipolar signal is rich with clock timing information.

On the view point of signal to noise ratio in a $\sqrt{f}$ transmission line, the (1, 1) partial response signalling is advantageous over the bipolar signalling since the former needs only to detect the mainlobe of the spectrum at the receive end of the system, while the latter needs to detect a wideband

mainlobe of the spectrum with a resultant decrease in signal to noise ratio. Therefore, the use of the partial response signalling to improve the signal to noise ratio results in a poor timing recovery performance, while the use of the bipolar signalling technique results in a low signal to noise ratio.

It is therefore an object of the present invention to provide a digital communication system which combines the advantages of the partial response signalling and bipolar coding techniques and eliminates the disadvantages of the prior art.

The digital communication system of the present invention comprises a transmitter including a (1, 0, -1) precoder for precoding a unipolar input digital data stream and a bipolar converter for converting the output signal of the (1, 0, -1) precoder into a bipolar signal, which is transmitted over a transmission line to a receiver. The receiver comprises a line equalization filter for equalizing losses encountered during propagation through the transmission line and a (1, 1) equalizer for equalizing the output signal of the equalization filter. A clock recovery circuit derives sample timing pulses from the output signal of the line equalization filter. In response to the sample timing pulses a decoder detects symbols from the output signal of the (1, 1) equalizer to generate a replica of the original digital data stream.

In a specific aspect of the present invention, the (1, 0, -1) precoder has a transfer function $1/(1 \oplus z^{-2})$ which is implemented by a modulo-2 adder for modulo-2 summing the unipolar input digital data stream with a second signal, and a delay line for introducing a delay time 2T to an output signal from the modulo-2 adder and supplying the delayed signal to the modulo-2 adder as the second signal, (where T represents intervals between successive symbols). The bipolar converter has a transfer function $1 - z^{-1}$ which is implemetned by a second delay line that introduces a delay time T to the output signal of the precoder and a subtractor for subtracting the output of the second delay line from the output of the precoder.

At the receiver, the (1, 1) equalizer has a transfer function $1 + z^{-1}$ which is realized by a third delay line for introducing a delay time T to the output signal of the line equalization filter and an adder for summing the output signal of the third delay line with the output signal of the line equalization filter and suppressed the higher frequency components of the output signal of the line equalization filter. The decoder provides modulo-2 conversion on the output of the (1, 1) equalizer so that bipolar format of the output signal of the (1, 1) equalizer is converted to unipolar format.

The present invention will be described in further detail with reference to the accompanying drawings, in which:

Fig. 1 is a block diagram of a prior art digital communication system;

Figs. 2a and 2b are graphic representations of spectral energy densities of conventional partial response and bipolar coding systems, respectively;

Fig. 3 is a block diagram of a digital communication system according to the present invention; and

Fig. 4 is a circuit diagram of a typical example of the line equalizing filter of Fig. 3.

DETAILED DESCRIPTION

Referring now to Fig. 3, a digital communication system according to the present invention comprises a (1, 0, -1) precoder 11 which receives a binary (unipolar) digital data stream S_n at input terminal 10 (where "n" represents a sequence number identifying each symbol or bit). Precoder 11 comprises a modulo-2 adder 20 and a delay line 21 of length 2T (where T is sample clock intervals between successive symbols) which is connected to the output of the modulo-2 adder 20. Modulo-2 adder 20 provides modulo-2 summation between the input data stream S_n and the output of the delay line 21. The (1, 0, -1) precoder 11 has a transfer function $D(z) = 1/(1 \oplus z^{-2})$ to convert the binary input data S_n into an intermediate data stream U_n which is represented by the relation $U_n = S_n \oplus U_{n-2}$.

The intermediate data stream U_n is supplied to a bipolar converter 12 formed by a delay line 22 of length T and a subtractor 23 which subtracts the output of delay line 22 from the output of precoder 11. Bipolar converter 12 has a transfer function $A(z) = 1 - z^{-1}$ with which it converts the intermediate data stream U_n into a bipolar data stream P_n which is represented by the relation $P_n = U_n - U_{n-1}$.

The bipolar data stream P_ns transmitted through a metallic transmission line 13 having a $\sqrt{f}$ transmission characteristic and applied to an analog-to-digital converter 14 where the amplitude of the bipolar signal is converted to a digital value and supplied to a line equalizing filter 15.

Line equalization filter 15 is provided to compensate for phase and amplitude distortions of the transmitted signal experienced during propagation through the transmission medium and generates a signal that corresponds in waveform to the bipolar input to the transmit end of the line 13.

Fig. 4 shows a typical example of the line equalizing filter 15. The digital data input X_n to be equalized by filter 15 is translatted into a series of outputs Y_n which is represented by:

$$Y_n = A_0X_n + A_1X_{n-1} + A_2X_{n-2} - B_1Y_{n-1} - B_2Y_{n-2}$$

where, A_0, A_1, A_2, B_1 and B_2 satisfy the following transfer function H(z) which approximates the transmission characteristic of the line 13:

$$H(z) = \frac{A_0 + A_1 z^{-1} + A_2 z^{-2}}{1 + B_1 z^{-1} + B_2 z^{-2}}$$

The bipolar output of line equalizer 15 feeds a (1, 1) equalizer 16 which comprises a delay line 24 of length T coupled to the output of filter 15 and an adder 25 which sums the output of delay line 24 with the equalized data stream to produce a (1, 0, -1) partial response signal Q_n which is represented by $Q_n = P_n + P_{n-1}$. The (1, 1) equalizer 16 has a frequency transfer function $H(f) = \cos(\pi f/f_0)$, (where $H(f) = 0$ if $|f| > f_c$) to suppress high frequency noise introduced by the transmission link 13 and exhibits a transmission characteristic $B(z) = 1 + z^{-1}$.

Thus, the transmission characteristic (C(z) of the system from the output of (1, 0, -1) precoder 11 to the input of decoder 17 is given by $C(z) = A(z)B(z) = 1 - z^{-2}$. Since the precoder 11 has the transfer function $D(z) = 1/(1 \oplus z^{-2})$, the transfer function E(z) of a path from the input of precoder 11 to the input of decoder 17 is given by $E(z) = (1 - z^{-2})/(1 \oplus z^{-2})$.

The output of the (1, 1) equalizer 16 is fed to a decoder 17 which perform the following modulo-2 binary conversion on the partial response waveform:

$$[E(z)]_{mod2} = \left[\frac{1 - z^{-2}}{1 \oplus z^{-2}}\right]_{mod2}$$

$$= \frac{[1 - z^{-2}]_{mod2}}{1 \oplus z^{-2}}$$

$$= \frac{1 \oplus z^{-2}}{1 \oplus z^{-2}} = 1$$

whereby, "±1" bit is converted to "1" bit and "0" bit is converted to "0" bit to produce a unipolar output data stream R_n at an output terminal 19 which is a replica of the original binary data stream is recovered at the receive end of the communication system. The output data stream R_n is given by $R_n = [Q_n]_{mod2}$ (where $R_n = 0$ if Q_n is even and $R_n = 1$ if Q_n is odd).

This precoding process transforms the input data in such a manner that the output level at the detector directly indicates the original data without comparison to the previous sample value.

If the input data stream $\{S_n\}$ is given by a bit stream {101100101}, then the following bit streams exist:

$\{U_n\}$ = {100101110}
$\{P_n\}$ = {1-101-1100-1}
$\{Q_n\}$ = {10-110010-1}
$\{R_n\}$ = {101100101} which is identical to the unipolar input data stream S_n. It is seen therefore that the communication system of the present invention is equivalent to a (1, 0, -1) partial response system.

The sample clock timing of the A/D converter 14, line equalizer 15, the (1, 1) equalizer 16 and decoder 17 is obtained by a clock recovery circuit 18 which derives its input from the clock-abundant bipolar signal from the output of line equalizer 15. Thus, pulse detection by decoder 17 can be made precisely at correct sample times. Since the (1, 0, -1) partial response signal is rendered tolerant of transmission distortions due to the reduction of the high frequency spectral components by the equalizer 16 which is tolerant of high frequency noise, pulse detection by decoder 17 can be performed with a high signal-to-noise ratio.

The foregoing description shows only one preferred embodiment of the present invention. Various modifications are apparent to those skilled in the art without departing from the scope of the present invention which is only limited by the appended claims. Therefore, the embodiment shown and described is only illustrative, not restrictive.

Claims

1. A digital communication system comprising:
a (1, 0, -1) precoder for precoding a unipolar input digital data stream;
a bipolar converter for converting the output signal of said (1, 0, -1) precoder into a bipolar signal and transmitting the bipolar signal through a transmission line to a receive end of the system;
a line equalization filter at said receive end for equalizing the losses of the transmitted signal experienced during propagation through said transmission line;
a (1, 1) equalization circuit for equalizing the output signal of said line equalization filter;
a decoder for detecting symbols from the output signal of said (1, 1) equalization circuit to generate a replica of said digital data stream; and
a clock recovery circuit for deriving sample timing

pulses from the output signal of said line equalization filter and supplying said timing pulses to said decoder.

2. A digital communication system as claimed in claim 1, further comprising an analog-to-digital converter for converting said bipolar signal transmitted through said transmission line into a digital data stream and applying the digital data stream to said line equalization filter.

3. A digital communication system as claimed in claim 1 or 2,
wherein said transmission line has a $\sqrt{f}$ attenuation characteristic, where f represents the frequency of the signal transmitted by the transmission line;
wherein said (1, 0, -1) precoder comprises a modulo-2 adder for modulo-2 summing said unipolar input digital data stream with a second signal, and a delay line for introducting a delay time 2T to an output signal from said modulo-2 adder and supplying the delayed signal to said modulo-2 adder as said second signal, where T represents intervals between successive symbols;
wherein said bipolar converter comprises a delay line for introducing a delay time T to the output signal of said precoder and a subtractor for subtracting the output of the last-mentioned delay line from the output of said precoder;
wherein said (1, 1) equalizer comprises a delay line for introducing a delay time T to the output signal of said line equalizing filter and an adder for summing the output signal of the last-mentioned delay line with the output signal of said line equalizing filter, said (1, 1) equalizer suppressing higher frequency components of the output signal of said line equalizing filter; and
wherein said decoder comprises means for providing modulo-2 conversion on the output of said (1, 1) equalizer so that bipolar format of the output signal of said (1, 1) equalizer is converted to unipolar format.

FIG. 1
PRIOR ART

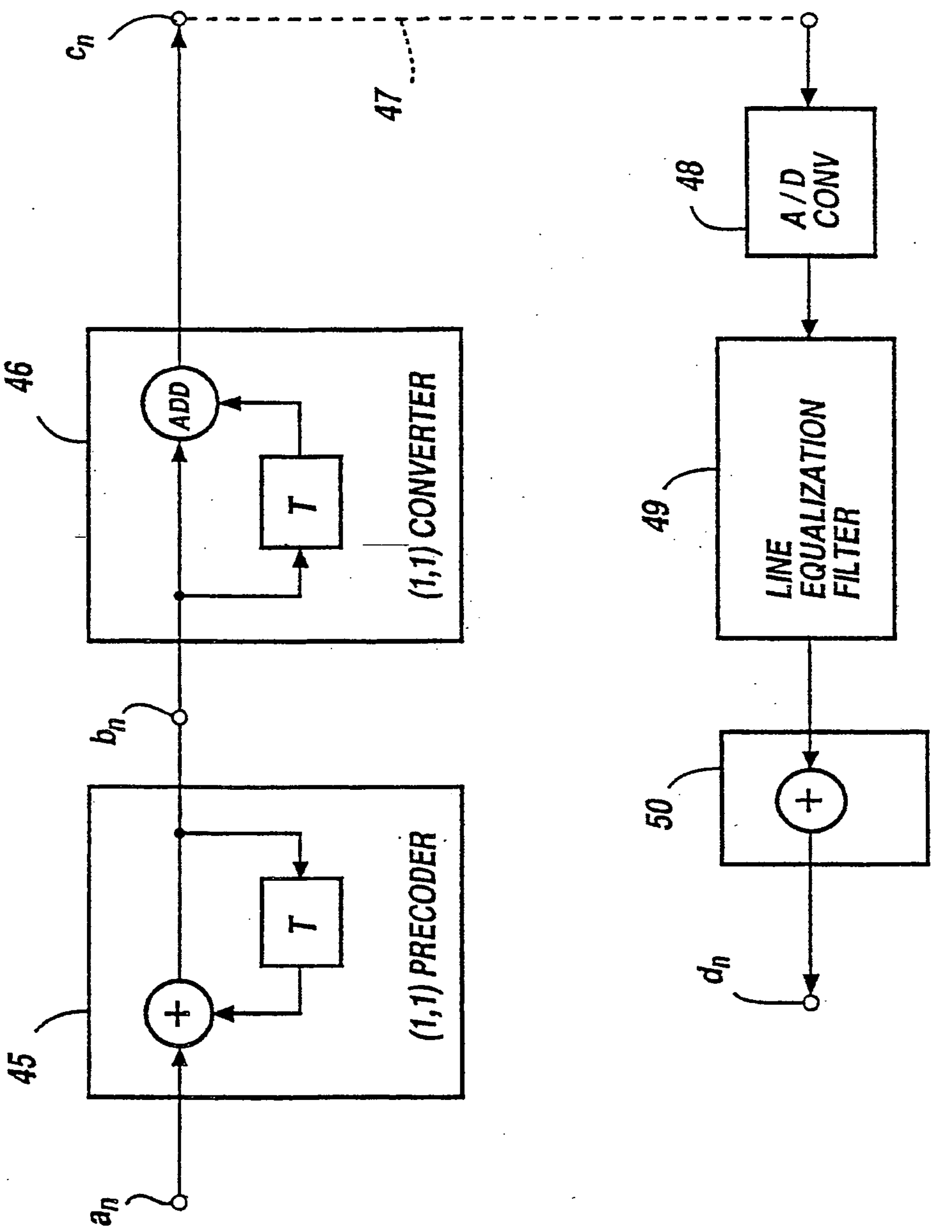


FIG. 2a
PRIOR ART

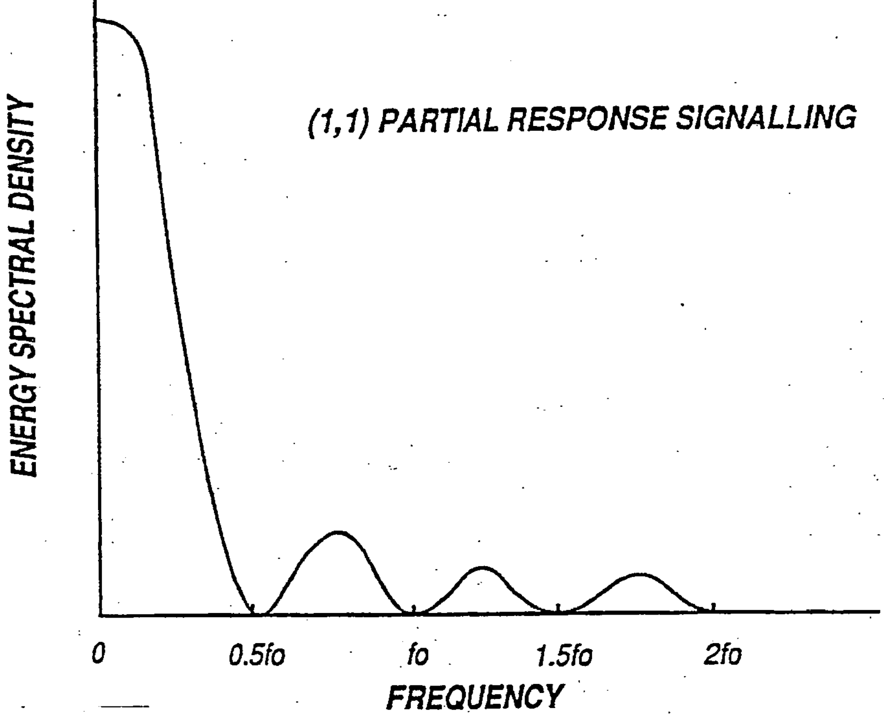


FIG. 2b
PRIOR ART

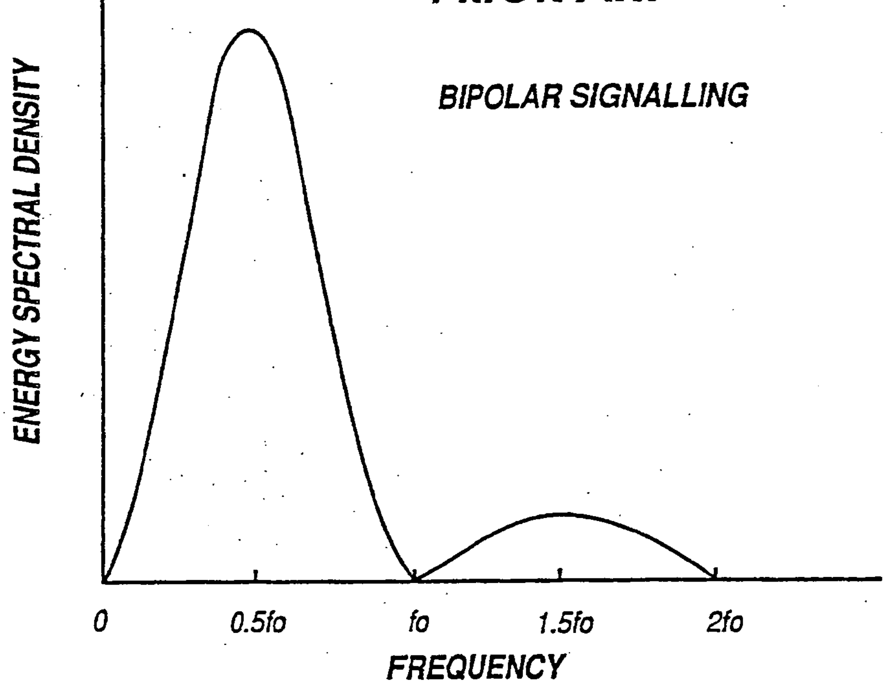


FIG. 3

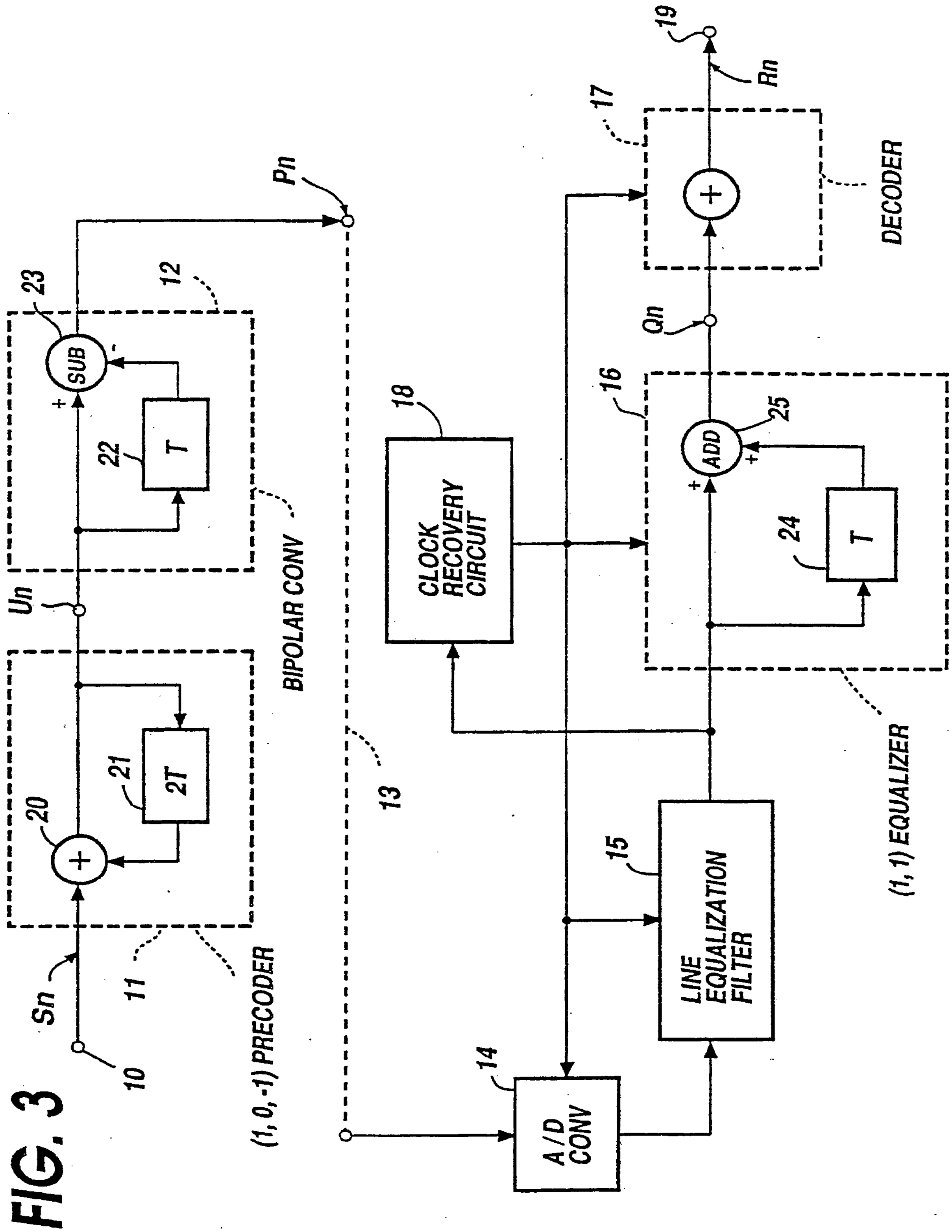
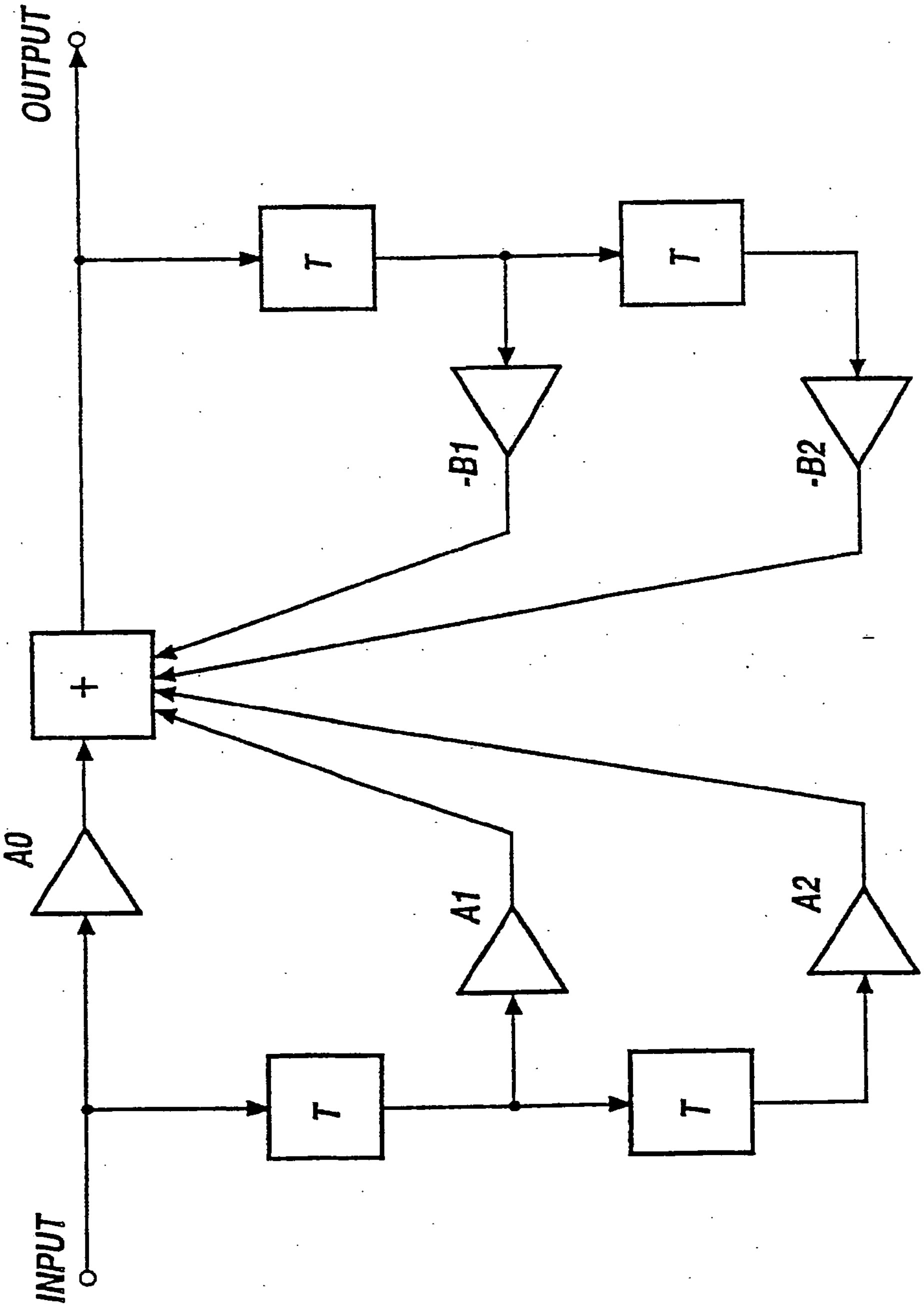

10
Sn
11
(1, 0, -1) PRECODER
20
21
2T
Un
BIPOLAR CONV
22
T
23
SUB
12
Pn
13
14
A / D CONV
15
LINE EQUALIZATION FILTER
18
CLOCK RECOVERY CIRCUIT
16
24
T
25
ADD
(1, 1) EQUALIZER
Qn
17
DECODER
Rn
19

FIG. 4



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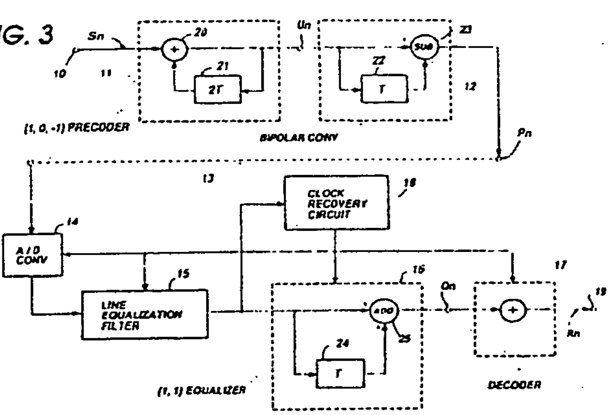

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EUROPEAN SEARCH REPORT

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
Y	GB-A-2 185 663 (STC) * Page 1, lines 20-24,45-53; page 3, lines 35-39 *	1	H 04 L 25/49
A		2,3	
Y	NEREM RECORD, Boston, US, 4th November 1966, pages 240-241, IEEE, New York, US; F.K. BECKER et al.: "A new signal format for efficient data transmission" * Page 240, left-hand column, line 43 - page 240, right-hand column, line 7; figure 3 *	3	
A	IDEM	3	
Y	IEEE TRANSACTIONS ON COMMUNICATIONS, vol. COM-33, no. 2, February 1985, pages 152-157, IEEE, New York, US; D.Y. KIM et al.: "A condition for stable minimum-bandwidth line codes" * Page 155, right-hand column, lines 6-10; figure 4 *	1	TECHNICAL FIELDS SEARCHED (Int. Cl.4)
A	IDEM	3	H 04 L
Y	REVIEW OF THE ELECTRICAL COMMUNICATION LABORATORIES, vol. 31, no. 2, 1983, pages 158-166, Tokyo, JP; R. KOMIYA et al.: "Digital service unit design" * Page 161, right-hand column, lines 11-18 *	1	

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	30-06-1989	CRETAINE P.A.

CATEGORY OF CITED DOCUMENTS

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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
A	IEEE TRANSACTIONS ON COMMUNICATION TECHNOLOGY, vol. COM-19, no. 6, December 1971, pages 1087-1100, New York, US; H. KOBAYASHI: "A survey of coding schemes for transmission or recording of digital data" * Page 1088, right-hand column, lines 7-31; page 1090, left-hand column, line 50 - right-hand column, line 5; figure 1 *	1	
A	IEEE TRANSACTIONS ON COMMUNICATIONS, vol. COM-35, no. 2, February 1987, pages 142-150, IEEE, New York, US; D.Y. KIM et al.: "Run-length-limited variants of duobinary and modified duobinary" * Figures 1(a),2(b) *	3	
			TECHNICAL FIELDS SEARCHED (Int. Cl.4)

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D : document cited in the application
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